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Title: The Search for a Neutron EDM at the SNS

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Search for a neutron EDM at SNS

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The nEDM Collaboration is developing an experiment to run at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory to search for the neutron electric dipole moment (EDM) with a sensitivity of $< 10^{-27}$ e cm based on the scheme proposed by Golub and Lamoreaux. The collaboration has been working on a various R&D experiments to establish the technical feasibility of the experiment and to guide the design of the apparatus. The collaboration has also been working towards finalizing the engineering of the experimental apparatus. In this talk, the principle of the experiment and the status of the project will be presented.

The Search for a Neutron EDM at the SNS

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The 8th UCN Workshop
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St. Petersburg - Moscow

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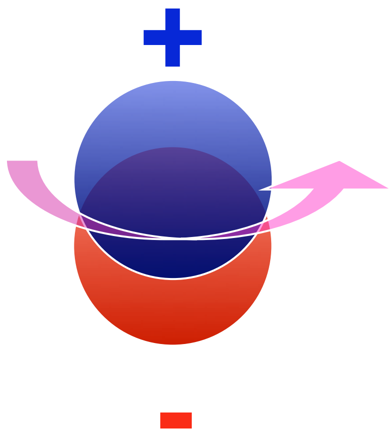
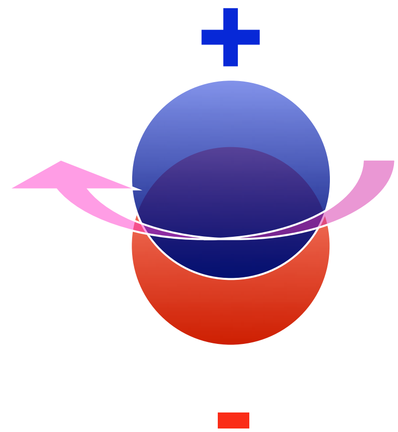
Outline

- Introduction
- Method of the nEDM experiment
- Design of the experiment
  - Engineering design
- Status of the experiment
  - Technical developments
  - Projected sensitivity
  - Schedule
- Summary

Electric Dipole Moment

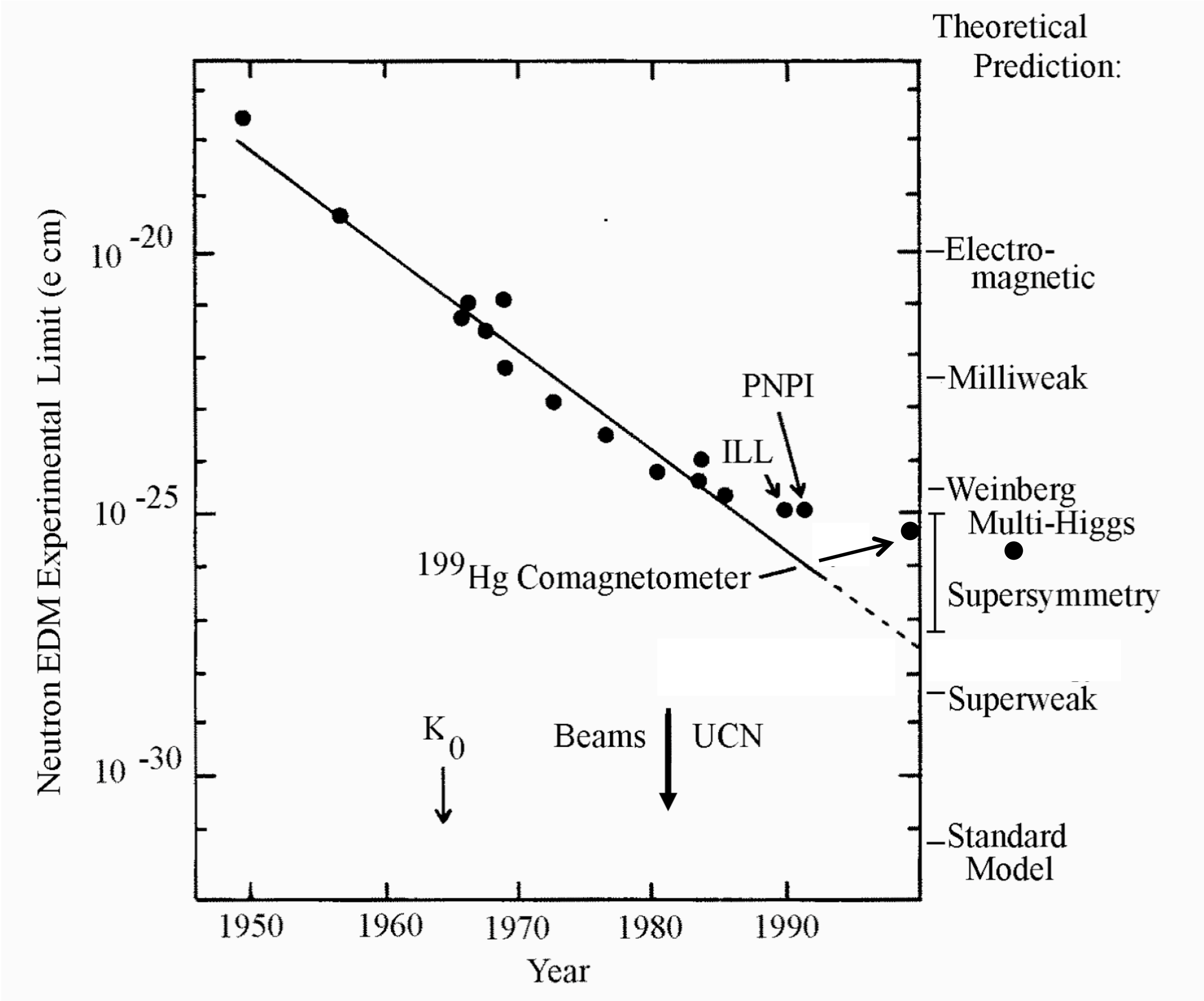




P or T reversed state

- EDM is a P and T (therefore CP) violating quantity
- Standard model value: $d_n \sim 10^{-32} – 10^{-31}$ e·cm
  (Small! Ideal probe for new Physics)
- Present limit: $d_n < 3.0 \times 10^{-26}$ e·cm (PRL **97**, 131801 (2006))

Evolution of EDM Experiments



Neutron’s Electric Dipole Moment

- EDM is P, T odd
- n-EDM is a sensitive probe of new sources of CP violation
  - EDM due to the SM is small because in the SM, CP violation only occurs in quark flavor changing processes to the lowest order.
  - Most extension of SM naturally produce larger EDMs because of additional CP violating phases associated with additional particles introduced in the model.
- Strong CP problem
  - The limit on the CP violating term in the QDC Langrangian (from n-EDM) is very small
  - One proposed remedy, Peccei-Quinn symmetry, predicts axions. However, axions have not been observed.
- Baryon Asymmetry of the Universe provides additional motivation

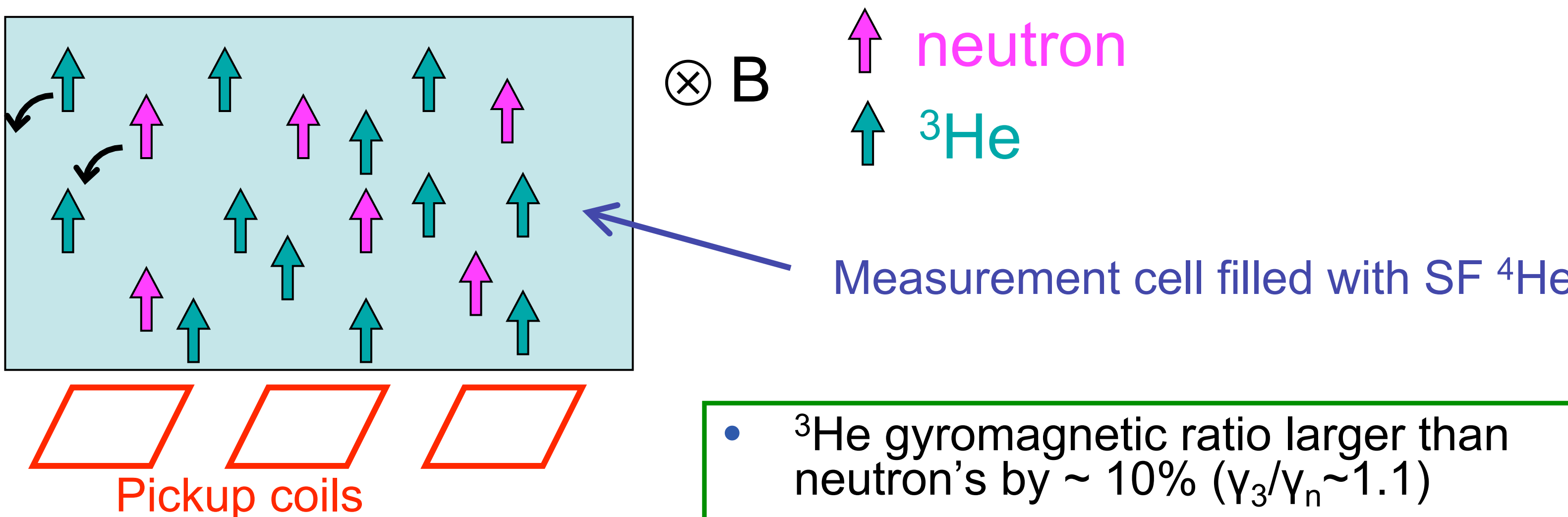
nEDM Experiment Method Overview

Experimental Concept: Golub& Lamoreaux, Physics Reports **237**,1,1994

- In situ production of UCN from 8.9 A cold neutron beam via superthermal process
- Higher electric fields expected to be achievable in LHe
- Use of ^{3}He as comagnetometer (a polarized atomic species within the same storage volume as the neutrons that provides a nearly exact spatial and temporal average of the magnetic field affecting the neutrons over the storage period)
- Use of ^{3}He as spin analyzer for the neutron
- Two complementary approaches to looking for the neutron EDM signal (effect of **d•E**)
  - Free precession method
  - Dressed spin method

Free precession method

A dilute admixture of polarized ^{3}He atoms is introduced to the bath of SF ^{4}He ($x = N_3/N_4 \sim 10^{-10}$ or $\rho_{3He} \sim 10^{12}$/cc)



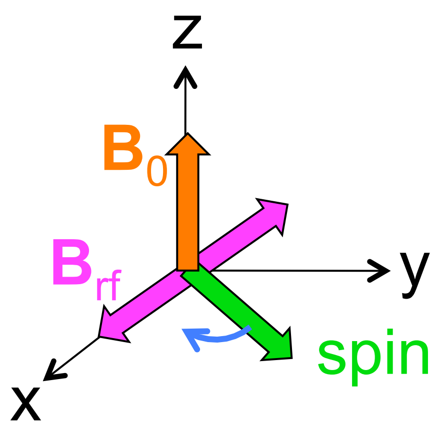
Change in magnetic field due to the rotating magnetization of ^{3}He detected by SQUID magnetometers

- ^{3}He gyromagnetic ratio larger than neutron's by ~ 10% ($\gamma_3/\gamma_n \sim 1.1$)
- Neutron absorption on ^{3}He highly spin dependent ($\sigma_{\uparrow\downarrow} >> \sigma_{\uparrow\uparrow}$)
- Reaction product of n+^{3}He→p+t generates UV (~80 nm) scintillation light in SF ^{4}He

Scintillation light from n-^{3}He capture reaction provides a measurement of $\omega_3-\omega_n$

Signature of EDM appears as a shift in $\omega_3-\omega_n$ corresponding to the reversal of ***E*** with respect to ***B*** with no change in ω_3

Dressed spin method



A strong non-resonant RF field

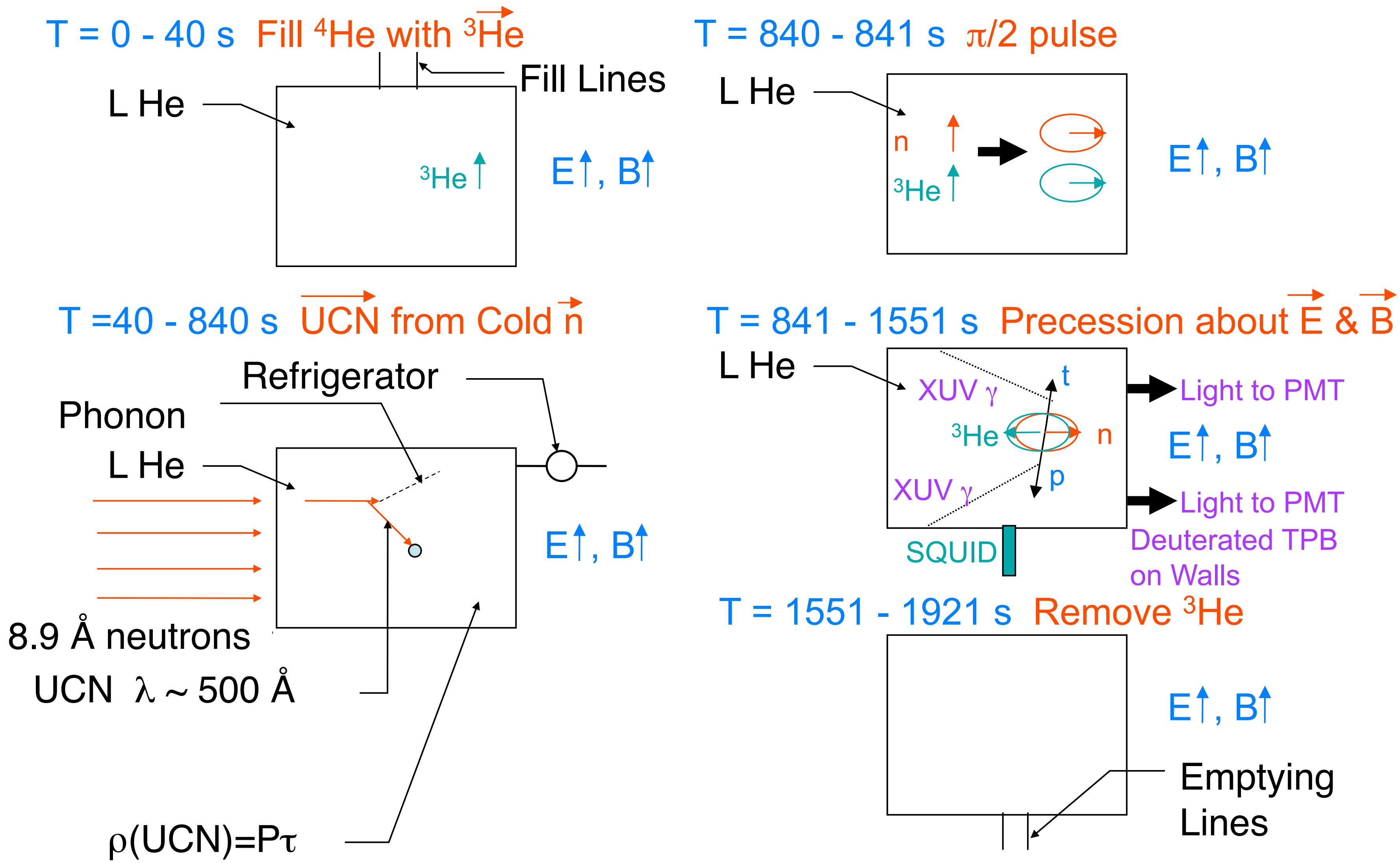
$$\mathbf{B_{rf}} \perp \mathbf{B_0},\ \mathrm{B_{rf}} >> \mathrm{B_0},\ \omega_{rf} >> \omega_0$$

- By applying a strong non-resonant RF field, the gyromagnetic ratio can be modified or "dressed" such that

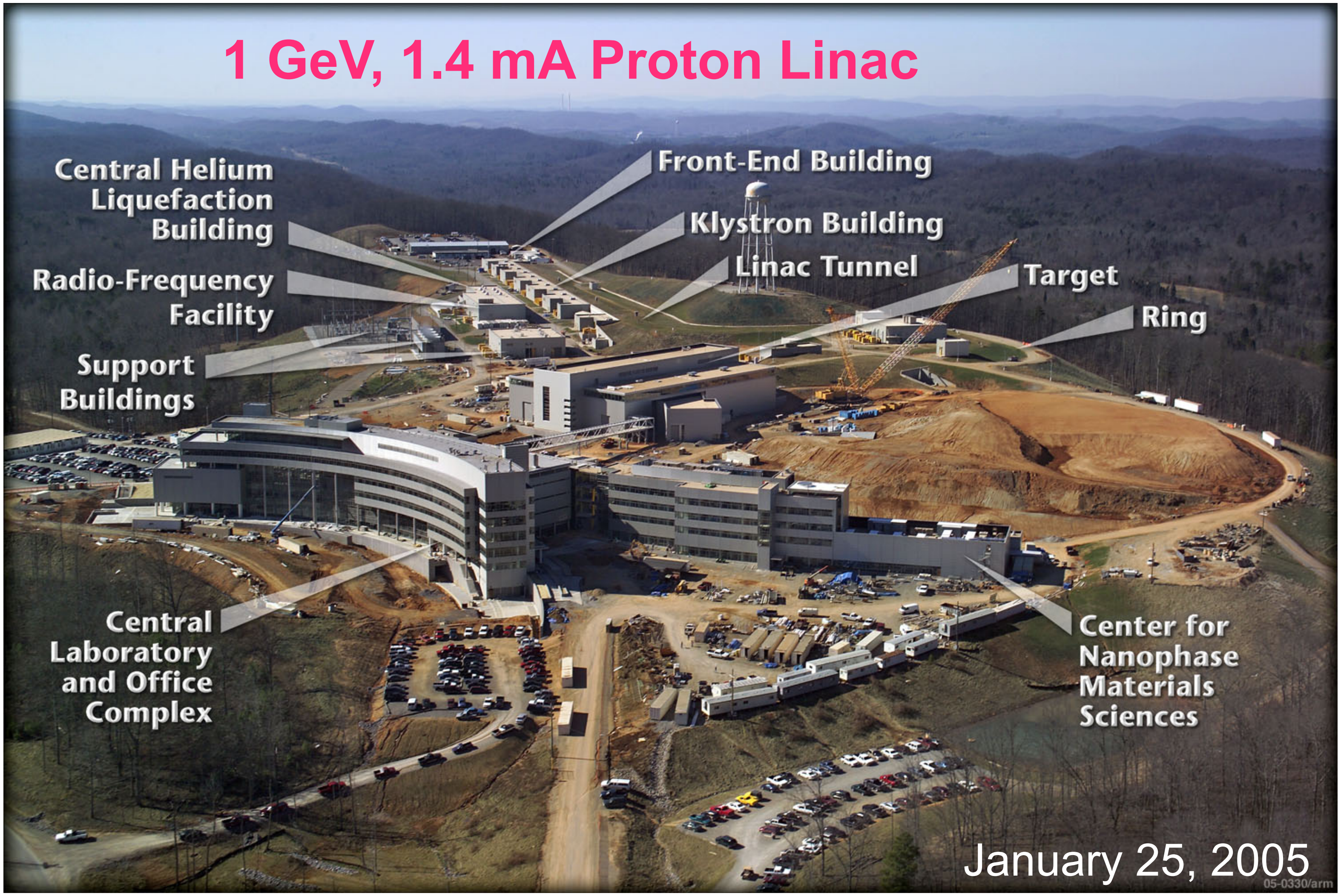
$$\gamma' = \gamma J_0\left(\gamma B_{rf} / \omega_{rf}\right)$$

- For a particular value of the dressing field (critical dressing), the neutron and ^{3}He have the same "effective" magnetic moments.
- Can tune the dressing parameter until the relative precession is zero (no scintillation light). Signature of EDM appear as a shift in this parameter corresponding to the reversal of **E** with respect to $\mathbf{B}_0$
- Provides access to EDM that is independent of SQUID magnetometers and independent of variations of the ambient B-field

Experiment Cycle

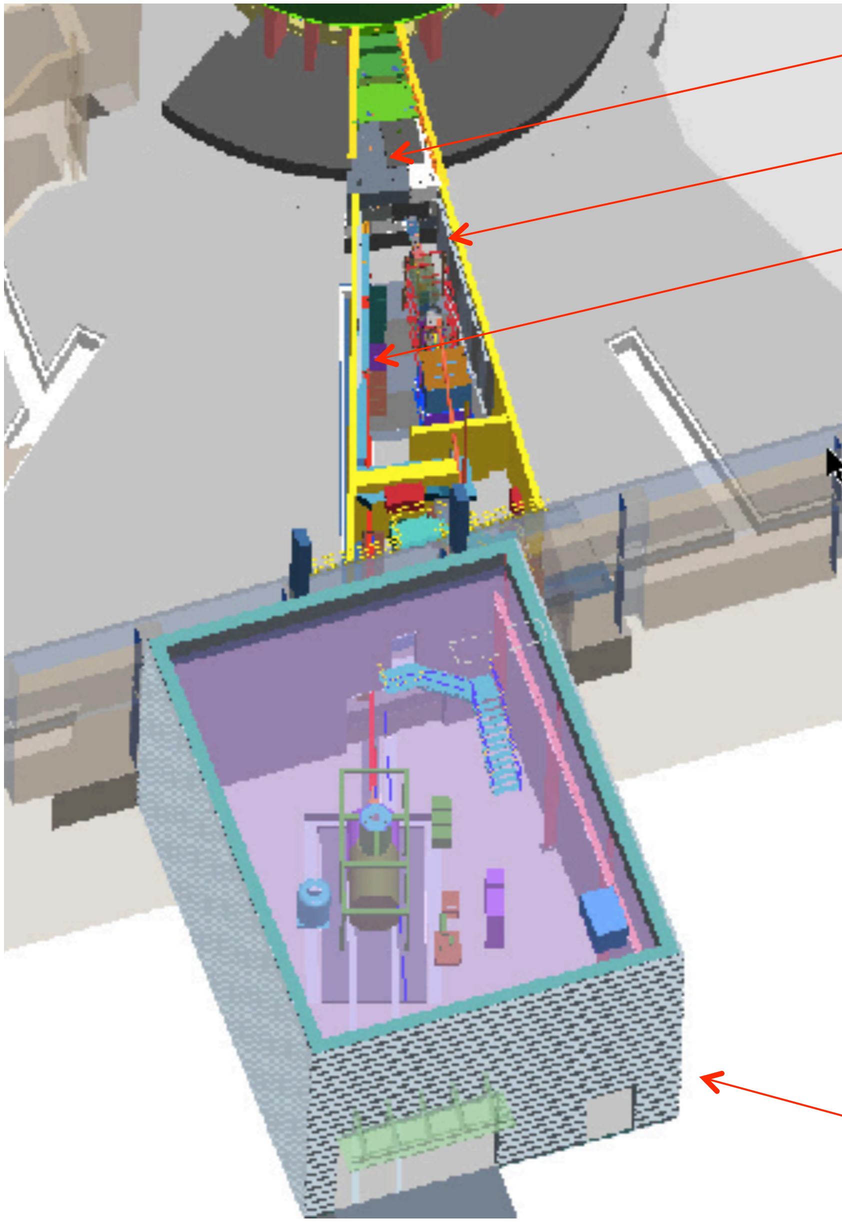


Spallation Neutron Source (SNS) at ORNL



•SNS construction completed: 2006

Fundamental Neutron Physics Beamline (FNPB)



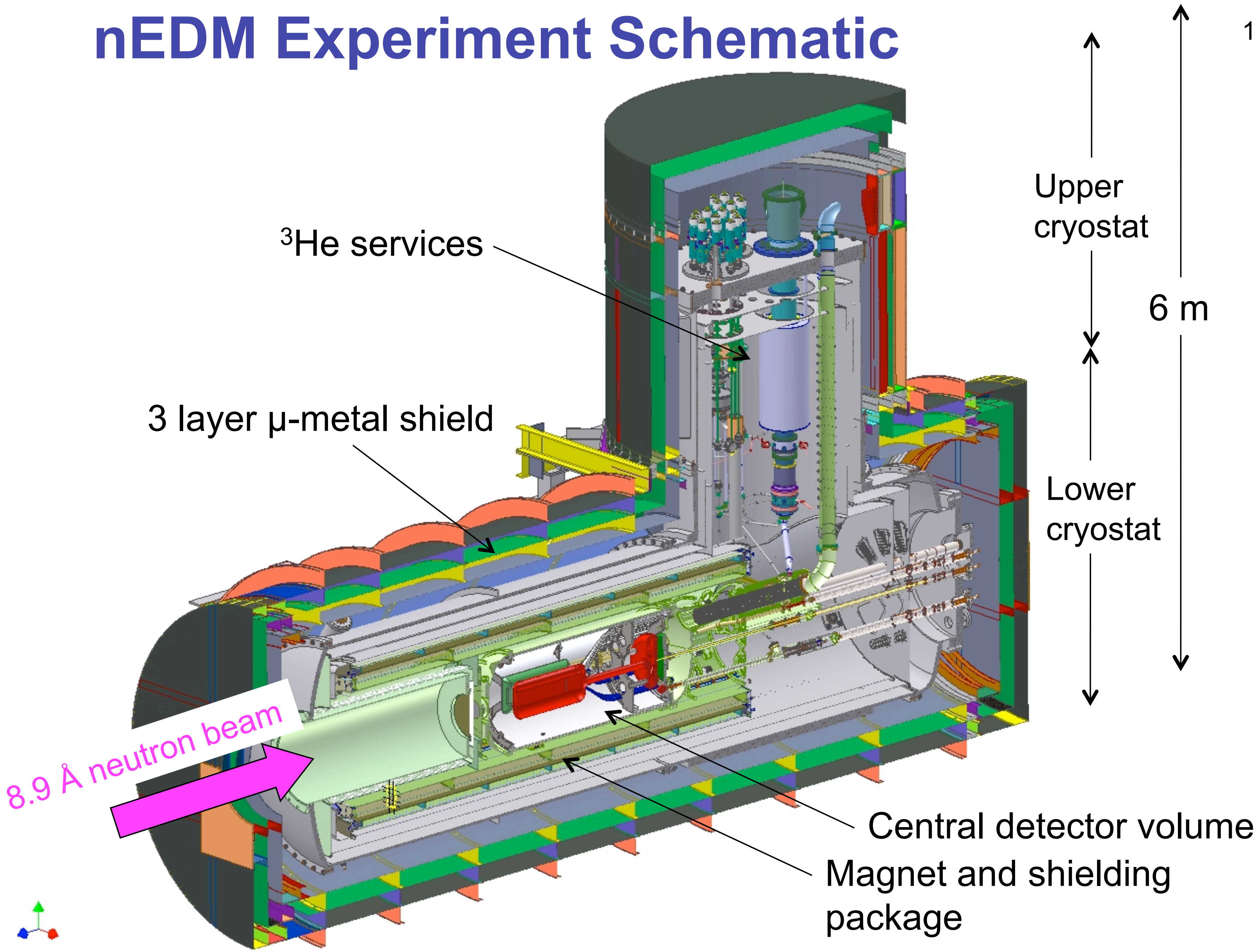
8.9 Å monochrometer

Cold beam line

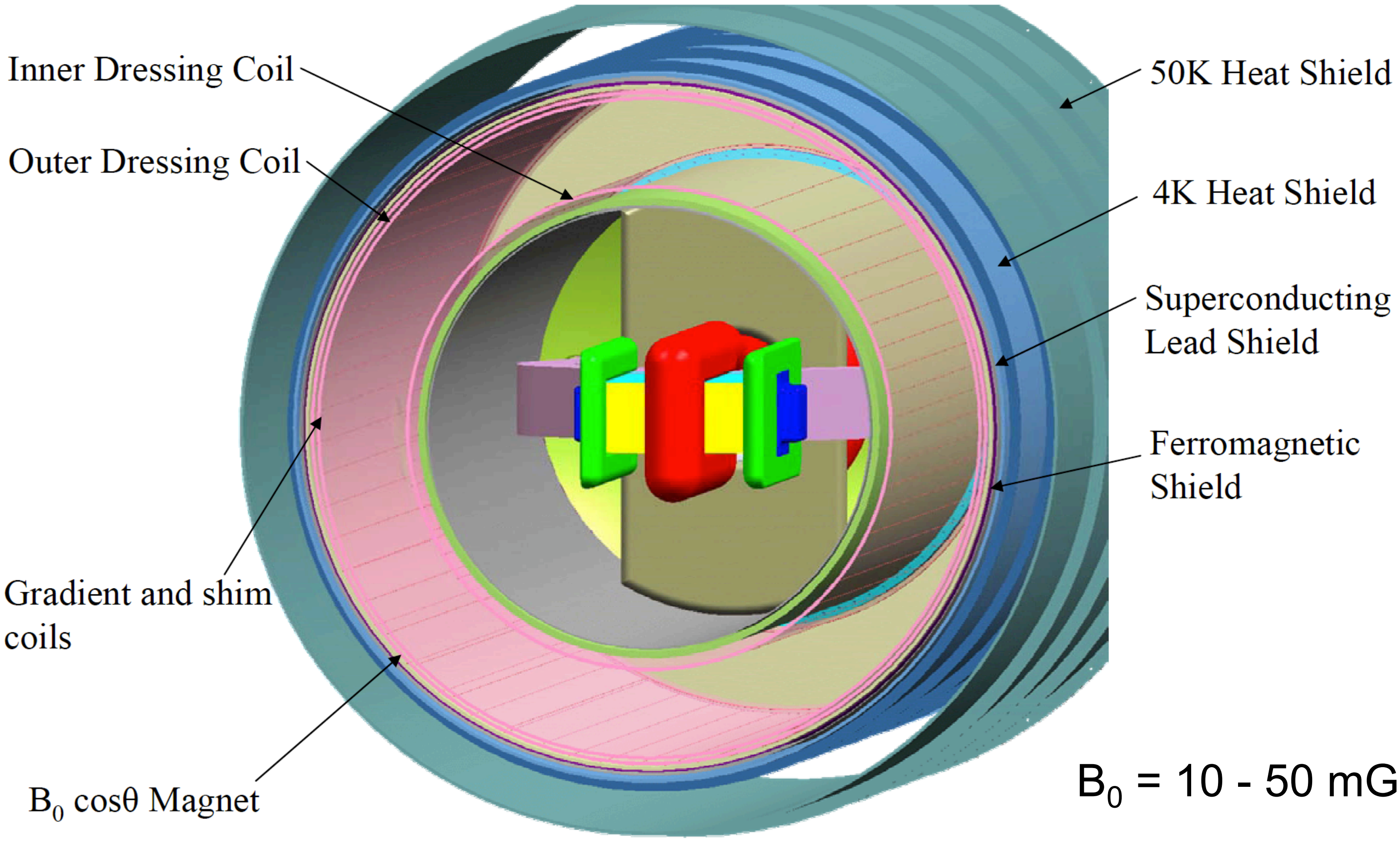
8.9 Å beam line

External nEDM building
(completed Nov 2009)

nEDM Experiment Schematic



Magnet System

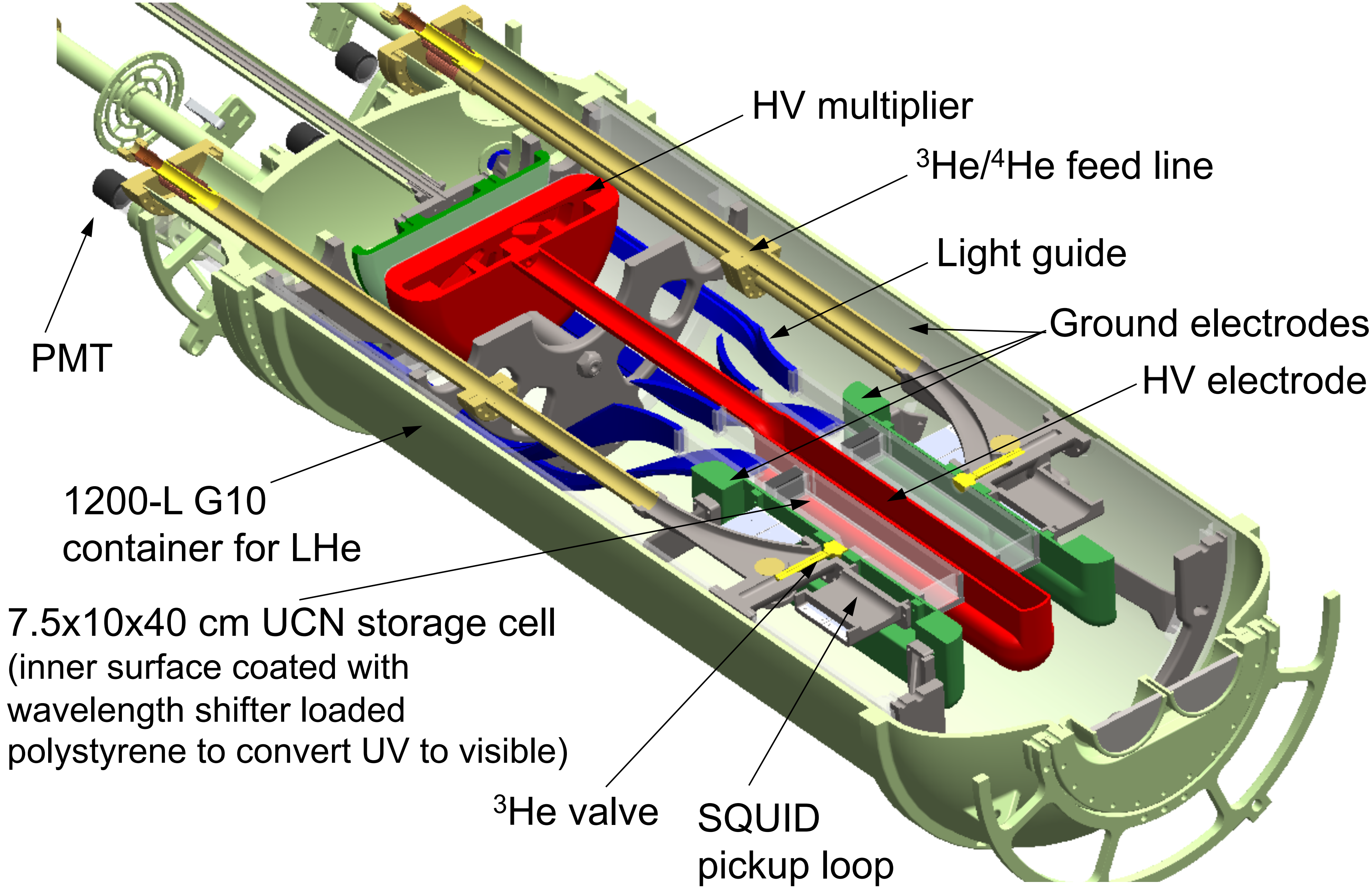


B_0 = 10 - 50 mG

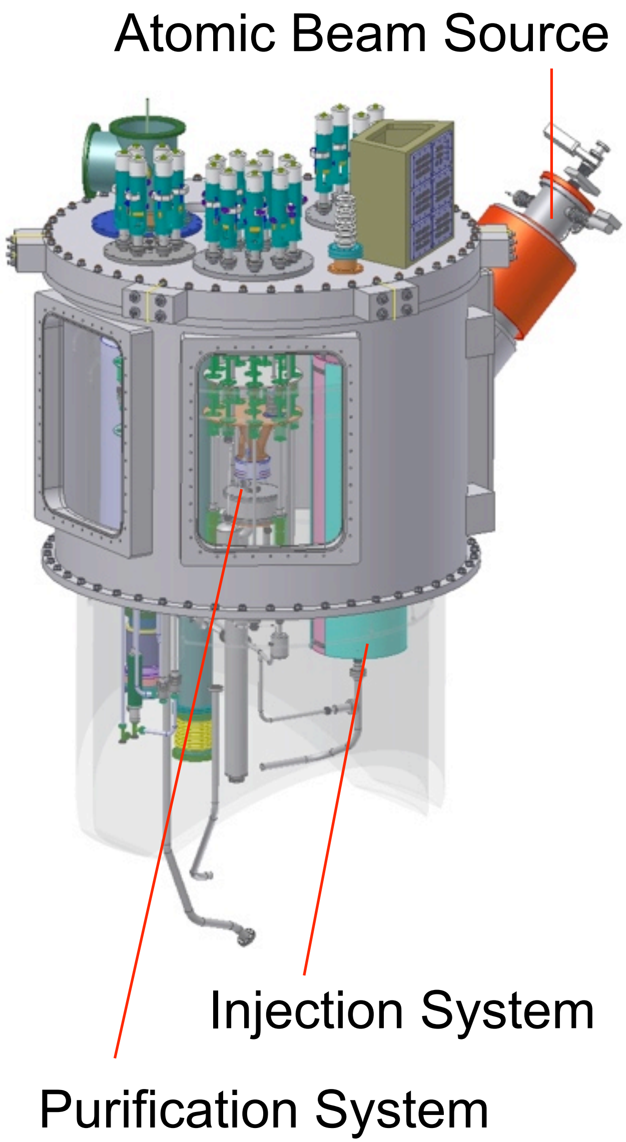
Uniformity requirements:

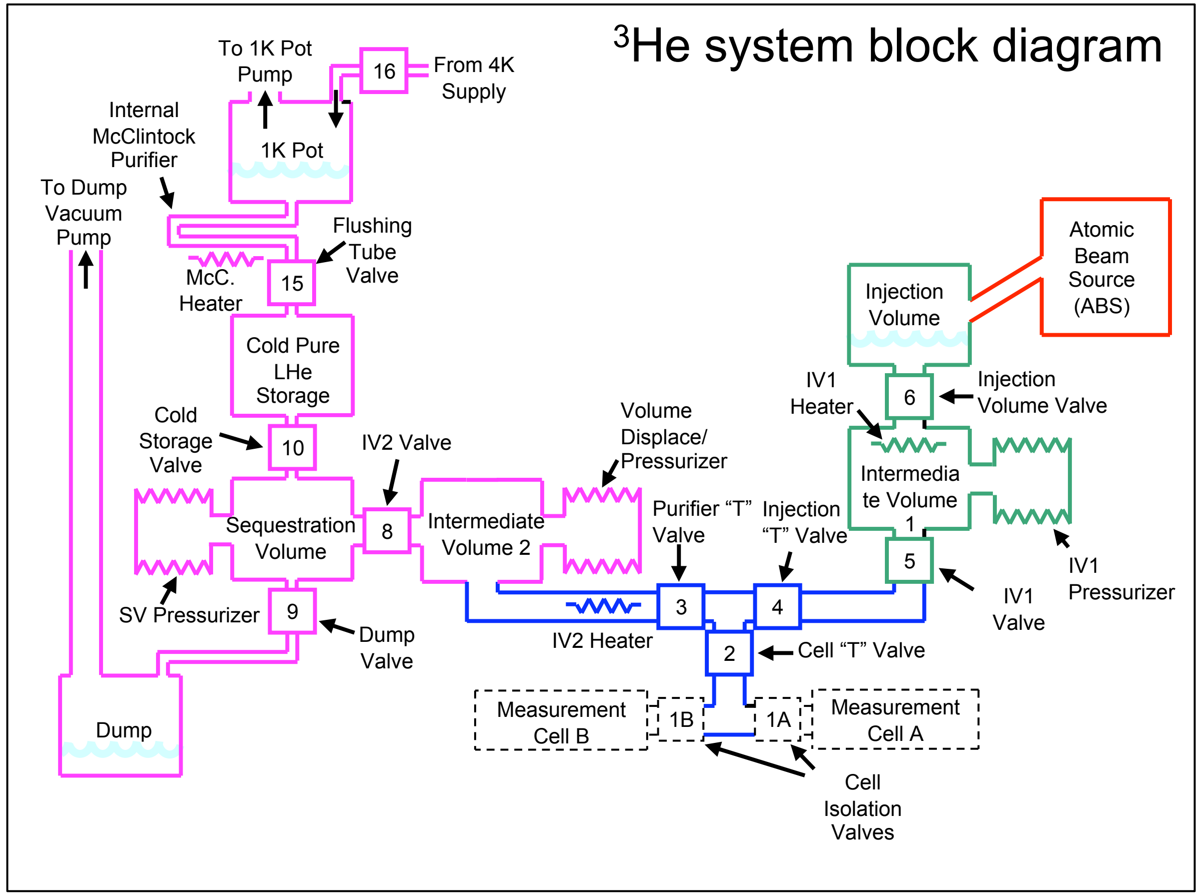
- Uniformity of 5×10^{-4} from relaxation times for the polarized neutrons and ^{3}He
- $< \partial B_x/\partial x > \; < 0.05$ μgauss/cm, $< \partial B_z/\partial z > \; < 0.1$ μgauss/cm, $< \partial B_y/\partial y > \; < 0.1$ μgauss/cm from geometric phase effects.

Central Detector System



^{3}He Services





- Heat flush and diffusion methods is used to move ^{3}He
- ^{3}He flow is controlled by heaters, valves, and pressurizers.

Technical challenges and developments

Challenges

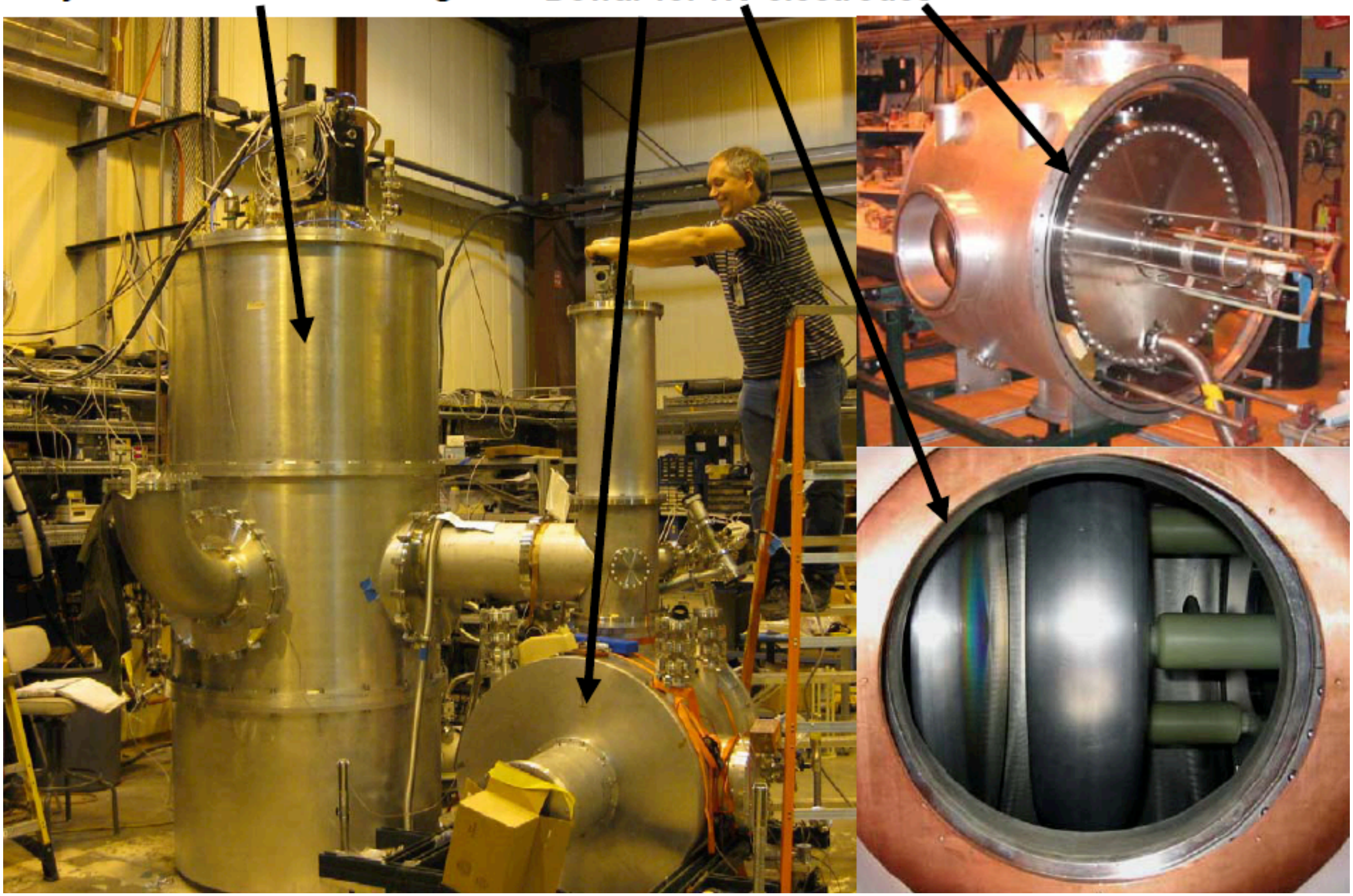
- Central detector module @ 0.3 –0.45K
- Magnet module @ 4K
- Eddy currents in conductors due to dressing field RF
- Stringent B-field uniformity requirements
- SQUIDs operation near HV
- Materials of cell and ^{3}He transport must maintain neutron & ^{3}He polarization

Developments

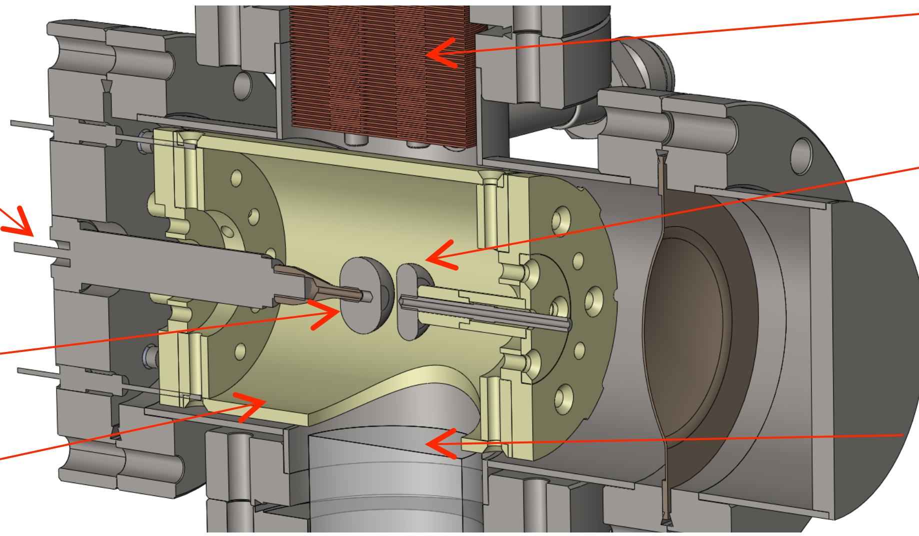
- Polarized ^{3}He Atomic Beam Source tested
- Relaxation time of ^{3}He on deuterated polystyrene walls (doped with dTPB) measured
- Progress towards HV tests at low temperature
- Superfluid He valves tested
- Magnetic field uniformity measured with ½ scale magnet
- HV dependence of scintillation light production measured
- Progress towards neutron storage time measurement
- Progress in detailed simulation of the experiments
- Progress towards ^{3}He injection test
- Progress towards heat flush test
- ….

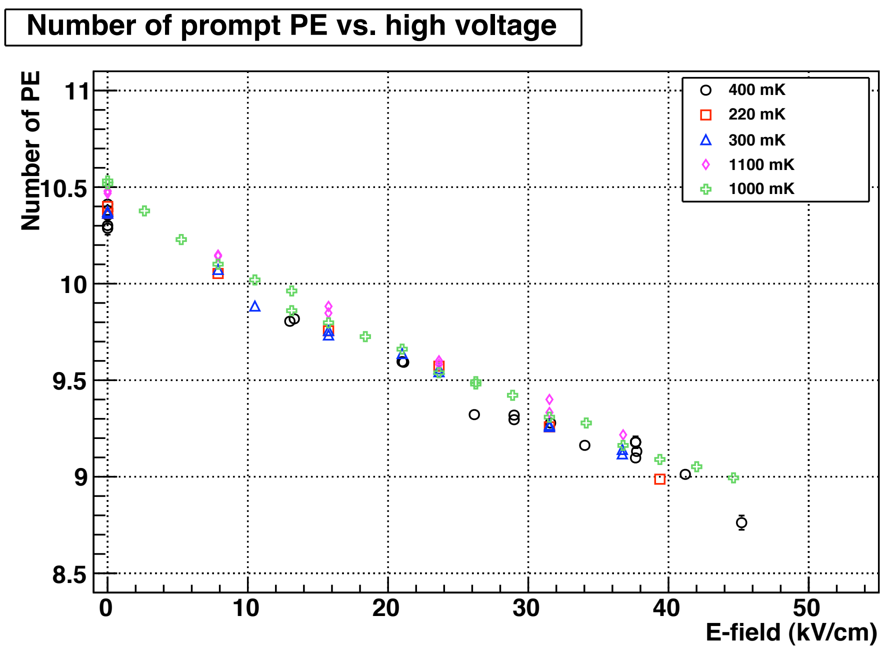
HV test stand

Cryostat with dilution fridge **Dewar for HV electrodes**



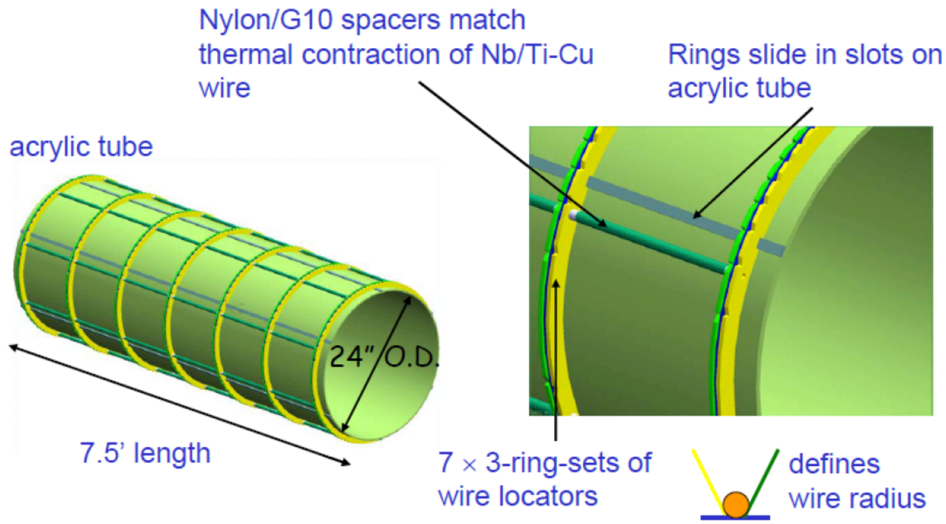
Liquid helium scintillation in an electric field

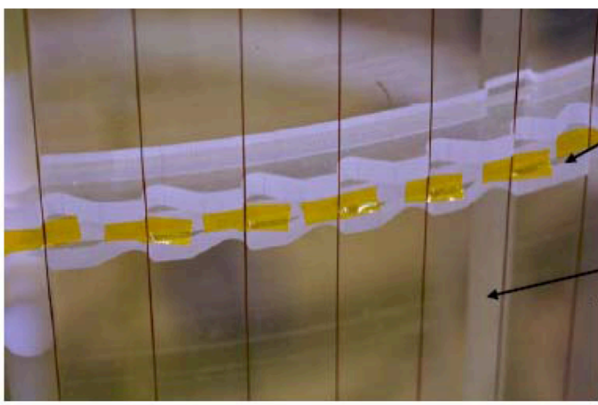




- Liquid helium scintillation intensity was measured using an α source as a function of the electric field strength up to ~ 45 kV/cm for temperatures between 0.2-1.1 K.
- Scintillation intensity reduces by ~ 15% at 50 kV/cm.
- The number of photoelectrons from scintillation light was consistent with the expected value.

B_0 coil development (1/2 scale prototype)

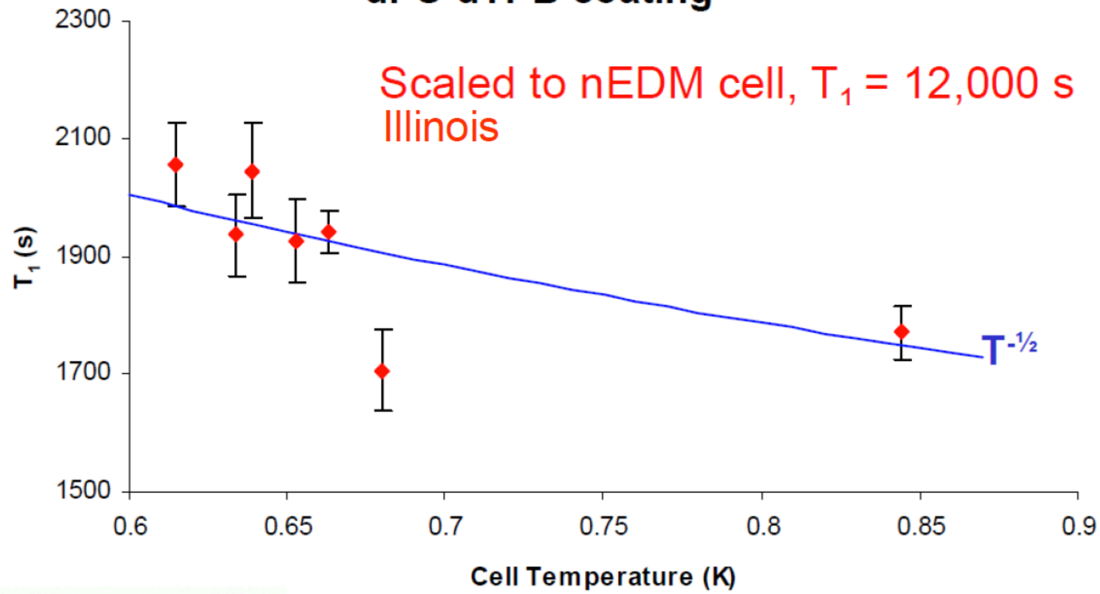




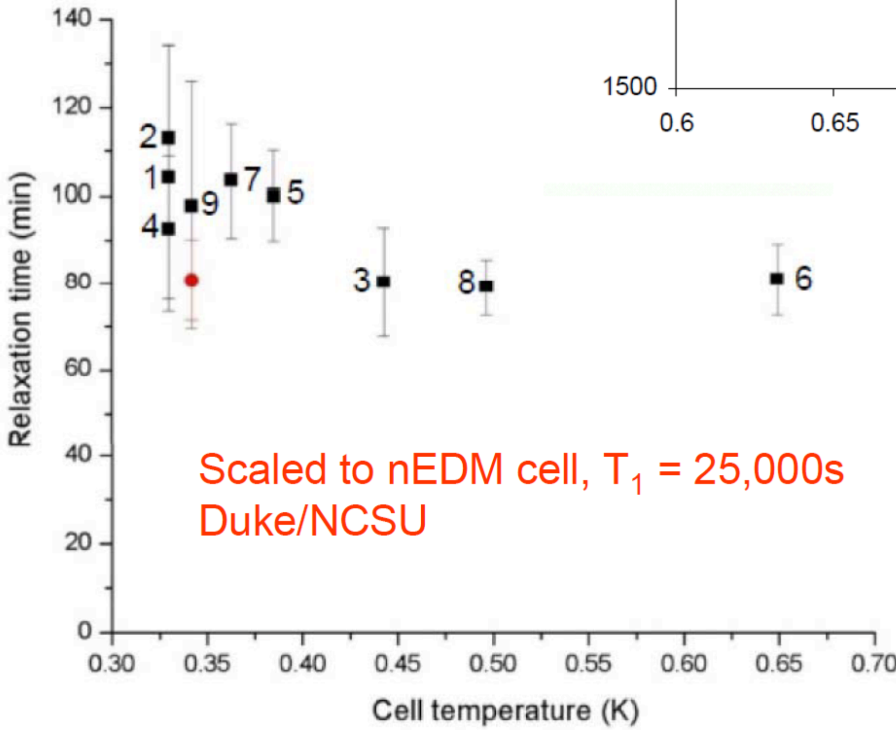
A ½-scale B0 coil prototype achieved the necessary uniformity at room temperature. Tests at 4K are underway.

Polarized ^{3}He wall relaxation

Need T_1 > 10,000s



Scaled to nEDM cell, T_1 = 12,000 s
Illinois

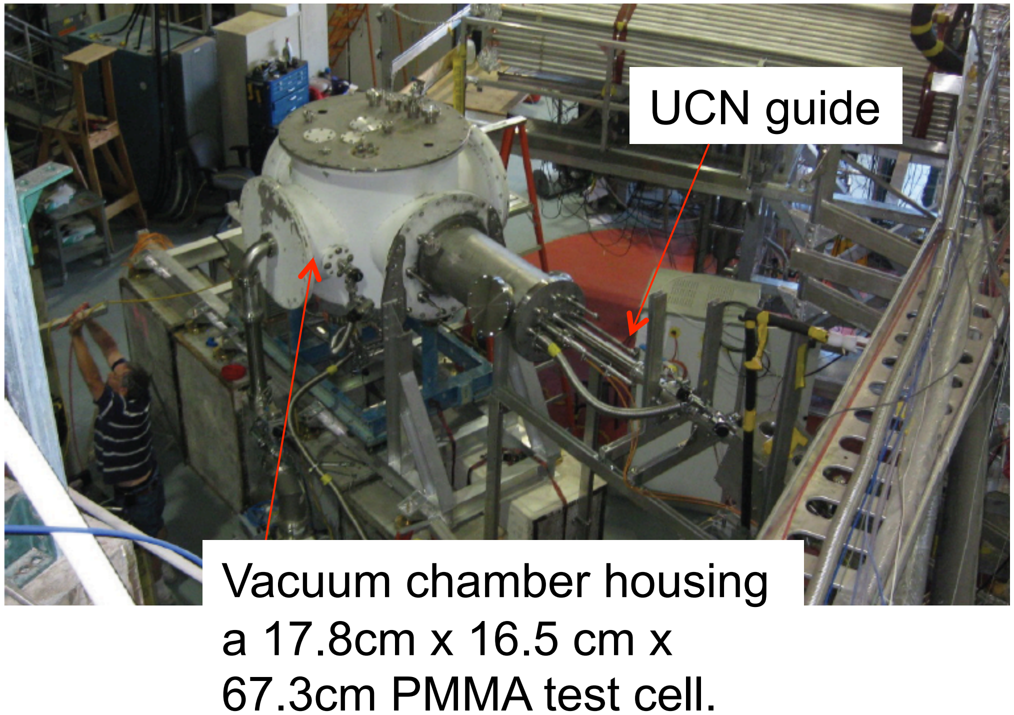


Scaled to nEDM cell, T_1 = 25,000s
Duke/NCSU

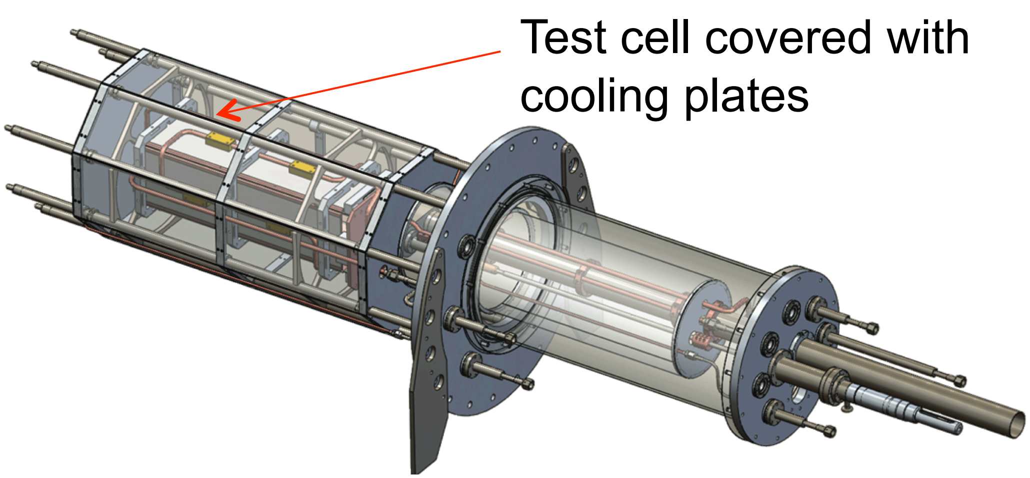
Cryogenic non-metalic superfluild valves

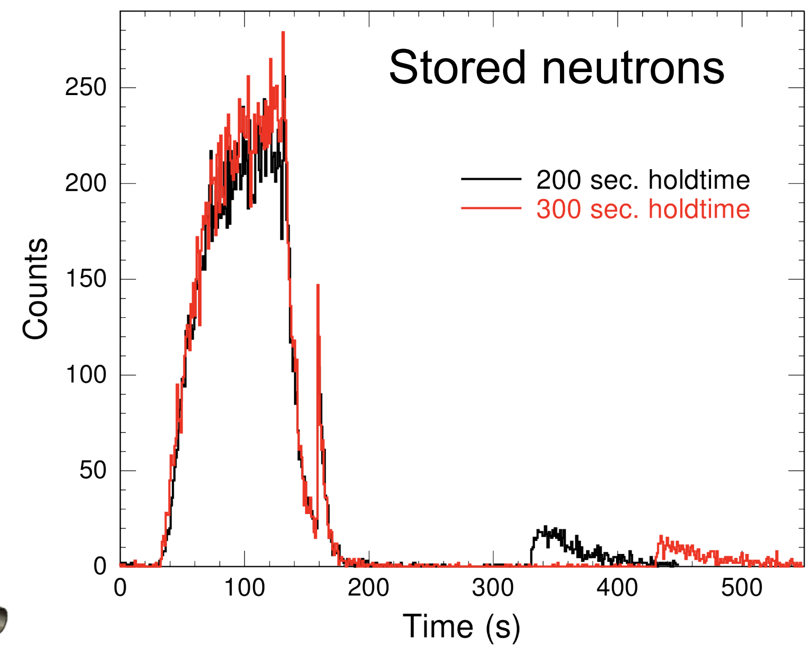
- Metallic construction would cause magnetic field non-uniformities and depolarization.
- 1” diameter needed for 3He transport.
- The body is made from Torlon.
- The boot and seat are made from Vespel.
- Successfully tested to seal superfluid He (1.7 K) for 10,000 cycles.

Neutron storage time measurement at LANSCE SD2 UCN source



- Goal: to measure the neutron storage time in a dPS coated cell at T < 20K.
- Status: apparatus, including the cell valve and the cell cooling mechanism, has been shown to work. A run with a dPS coated cell planned by the end of the year.





Projected sensitivity

- Projected statistical sensitivity (limited by the neutron density in the storage cells):

  90% CL $\sigma_d < (3\text{-}5) \times 10^{-28}$ e-cm in 300 live-days

  (using the cold beam line)

- Expected systematic effects:

Source	δd_n (e cm)	Comments
Linear E×v (geometric phase effect)	$< 1 \times 10^{-28}$	Uniformity of B_0
E×v from rotational neutron flow	$< 1 \times 10^{-28}$	E-field uniformity
Uncompensated leakage current effects	$< 0.2 \times 10^{-28}$	1 nA leakage currents
Heat from leakage currents	$< 1.5 \times 10^{-28}$	1 pA leakage currents correlated with E field
Quadratic E×v	$< 0.5 \times 10^{-28}$	$\delta E/E < 1\%$
Miscellaneous	$< 1 \times 10^{-28}$	

  – Various means by which to tackle potential systematic effects: ^{3}He comagnetometer, dressed spin method, and characterization of geometric phase effect by variation of the temperature.

Geometrical phase effects

Pendlebury et al. Phys. Rev. A **70**, 032102 (2004).
Lamoreaux and Golub, Phys. Rev. A 71, 032104 (2005).
Barabanov, Golub, and Lamoreaux, Phys. Rev. A **74**, 052115 (2006).
Golub,Swank and LamoreauxarXiv:0810.5378

- Effects exist both for UCN and 3He and are different between UCN and 3He
  - UCN: $\omega_0 >> \omega_r$ (ω_r=orbital frequency).
  - 3He: $\omega_0 << \omega_r$. The collision mean free path is strongly is strongly temperature dependent. Running at different temperatures helps determine the size of the effect.

Schedule

- 2011: Start procurement of long lead time items, cost and schedule baselined
- 2012: Final engineering design and drawings completed, start construction
- Start cryogenic testing: 2013-2014
- Install subsystems into the experiment: 2014-2016
- Start commissioning: 2017

Summary

- A neutron EDM experiment at SNS is underway.
- The experiment at the SNS has unique and powerful capabilities for addressing some systematic effects.